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Fertilizer management for forage crops in central Alberta

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Fertilizer management for forage crops in central Alberta

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SUMMARY

Land for forage production in Alberta represents approximately 50% of the total agricultural land of the province, however, only 25% of the improved pasture and hay land receives fertilizer nutrient applications. Efficient forage fertilization is dependent upon the producer deciding on the type, timing and amount of fertilizer needed for optimum production. One or more of the four major nutrients, nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) may be limiting for optimum forage production.

Grass forage crops have a high N requirement and respond well to N fertilizer application, while responses to P, K and S fertilizer are moderate and variable. Rates, times and methods of N fertilizer application have a strong influence on forage yield response and the effectiveness of the N fertilizer used. In moist areas of the province good yield response will occur up to 200 kg N/ha, while for dry areas maximum N rates are closer to 100 kg N/ha. Smaller annual N applications will produce higher and more consistent yields of dry matter than will an equivalent single large N application made every 3 or 4 years. Annual split applications of N fertilizer may produce more uniform forage production in moist areas and under irrigation, whereas in the drier areas split applications are not recommended. Of the N sources available, ammonium nitrate produces higher dry matter and protein yield than urea when broadcast on surface, but the effectiveness of urea can be improved by disc-banding below the soil surface. Early spring applied N is generally more effective than N applied in fall or late spring. Economic analysis suggests that relatively high rates of N fertilizer can be economical but the benefits are greatly affected by climate. For P-deficient soils, P fertilizer that is broadcast and incorporated into the soil prior to establishment of a grass forage stand will remain available to the crop for several years but it is not as effective as annual broadcast applications of P. Applying moderate annual rates of P early in spring ensures adequate P levels for the entire growing season. Potassium and S fertilizers are essential for forage production on K- and S-deficient soils.

Legume forages have the ability to form a symbiotic relationship with N-fixing bacteria, which allows the legume crop to obtain its N needs through fixation of N from the atmosphere. Proper inoculation with N-fixing bacteria is critical for successful establishment of legume forages. As a result N fertilizer is usually not required by legume forages, however, P, K and S fertilizers may be essential to correct deficiencies. In general, legume forages will produce higher yields and use P more effectively where P is applied annually rather than from a single large application made at time of establishment that is intended to last several years. Annual surface applications of P to established forage stands may not become completely available in the year of application due to poor mobility of P. Adequate supplies of K are essential to ensure proper nodulation, regrowth and stronger winter hardiness. Under K-deficient soil conditions, legumes show yield benefit from annual broadcast applications of K fertilizer. Legume forages have a high S requirement for N-fixation, yield and protein content. On S-deficient soils, marked increases in yield and forage quality can be obtained from small annual applications of S.

Fertilizer management for mixed grass-legume forages is much more difficult than in the case with pure grass or legume stands. In general, stands with more than 80% grass should be

fertilized as a pure grass and stands with more than 80% legume should be managed as a pure legume forage. To maintain mixtures between 40 to 60% legume and thereby receive the benefits from N-fixing capabilities of the legume, limited amounts of N fertilizer should be applied but adequate levels of P, K and S must be maintained. Application of N fertilizer will stimulate grass production but can reduce the legume content of the stand. Small annual applications of P, K and S fertilizers will correct deficiencies and produce higher and more consistent yields than an equal amount of single initial application intended to last several years.

The amounts of tame pasture forage production can have a direct effect on animal performance. Fertilizer application to forage pastures shows substantial increases in animal gain and carrying capacity compared to pastures that receive no fertilizer.

Soil acidification can occur from the application of fertilizers to forage stands. Nitrogen application has a significant acidifying effect on the soil. The greatest effect occurs near the surface (0-5 cm), where both acidity and extractable aluminum (Al) increase with higher N rates. Ammonium nitrate is more acidifying than urea, while ammonium sulphate is the most acidifying N fertilizer. A single application of lime can effectively neutralize the excess acidity and improve forage yields for many years.

Soil testing is an effective tool for evaluating soil fertility status, diagnosing nutrient deficiencies, identifying potential soil salinity and acidity problems and providing the basis for fertilizer recommendations. Climate and soil type have a significant influence on the response of forage to fertilizer application. Recommendations for fertilizer application are affected by agro-climatic areas and forage type.

RÉSUMÉ

En Alberta, le sol disponible pour la croissance des fourrages représente environ 50% du territoire agricole de la province. De cette superficie, seulement 25% des pâturages et terres à foin amendés sont fertilisés. Pour que la fertilisation des fourrages soit efficace, pour obtenir une production optimale, et pour contrer des carences nutritionnelles en éléments essentiels tels que l'azote (N), le phosphate (P), le potassium (K) et le soufre (S), le producteur doit tout d'abord décider du type et de la quantité de fertilisant à utiliser ainsi que de la période appropriée pour l'épandage.

La culture des graminées fourragères nécessite un apport élevé en azote et réagi bien à l'utilisation de fertilisants azotés. Par contre la réaction aux fertilisants P, K et S est variable et modérée. La méthode, la période et le taux d'application du fertilisant azoté ont une influence importante sur le rendement des fourrages et l'efficacité du fertilisant azoté utilisé. Dans les régions humides de la province, on obtient un bon rendement en utilisant jusqu'a 200 kg d'azote/ha, alors que dans les régions plus sèches, la teneur maximale en azote serait de l'ordre de 100 kg/ha. Plusieurs applications annuelles d'azote produiront un rendement plus élevé et plus constant en matière sèche qu'une seule application équivalente faite à toutes les 3 ou 4 années. L'application annuelle fractionnée de l'azote peut produire un fourrage plus uniforme en régions humides et sous irrigation, mais n'est pas recommendée dans les régions sèches. Parmis les sources d'azote disponibles, l'emploi du nitrate d'ammonium épandu en surface est préférable à celle de l'urée et ce, pour un rendement élevé en matière sèche et en protéines. Mais l'efficacité de l'urée peut-être améliorée grâce à l'épandage en bandes par disque sous la surface du sol. De plus, l'application d'azote tôt au printemps est habituellement plus efficace qu'en automne ou tard au printemps. Des études suggèrent qu'un taux élevé de fertilisant azoté peut-être économiquement rentable mais que les effets bénéfiques dépendent du climat. Pour les sols pauvres en phosphate, l'engrais phosphaté épandu en nappes et incorporé dans le sol avant l'établissement d'un peuplement de graminées fourragères demeurera disponible pour les plantes pendant plusieurs années, mais n'est pas aussi efficace que l'épandage annuel de phosphate. L'application annuelle modérée de P tôt au printemps assurera une disponibilité de phosphate pour toute la saison de croissance. Les fertilisants potassés et soufrés sont essentiels pour la production de fourrages sur sols pauvres en K et S.

Les légumineuses fourragères ont la particularité de former une symbiose avec des bactéries fixatrices d'azote, et ce phénomène permet aux plantes d'obtenir l'azote directement de l'atmosphère par fixation. L'inoculation efficace de bactéries fixatrices d'azote est importante pour l'établissement des légumineuses. Même si aucun engrais azoté est nécessaire, les fertilisants P, K et S peuvent s'avérer essentiels pour corriger certaines carences. En général les légumineuses fourragères ont un meilleur rendement et utilisent P plus efficacement là ou il est appliqué annuellement plutôt qu'une seule application faite au moment de l'ensemencement et destinée à durer plusieurs années. L'épandage phosphatée annuelle en surface, pour l'établissement du peuplement fourrager, peut ne pas être complètement accessible durant l'année d'application due à la pauvre mobilité du phosphate dans le sol. Une quantité adéquate de potassium est nécessaire pour assurer une bonne nodulation, un redémarrage et une résistance à l'hiver adéquats. Les légumineuses sur sol pauvre en K ont un meilleur rendement lorsqu'elles bénéficient d'un épandage

en nappes annuel de fertilisant potassé. Les légumineuses ont de plus besoin de soufre pour fixer l'azote, pour un bon rendement et une bonne teneur en protéines. On peut accroitre le rendement et la qualité des fourrages sur sols pauvres en soufre par de petites applications annuelles de soufre.

La gestion des fertilisants pour les fourrages mixtes de graminées-légumineuses est plus complexe qu'avec ces cultures prises séparément. En général les cultures qui possèdent plus de 80% de plantes légumineuses sont considérées légumineuses pures. Pour maintenir des mélanges en légumineuses entre 40 et 60% et pour aussi bénéficier de la capacité de fixation de ces plantes, de petites quantités de fertilisant azoté devraient être appliquées tout en s'assurant de maintenir des taux appropriés en P, K et S. L'emploi d'engrais azoté stimule la production de graminées, mais peut réduire la quantité de légumineuses du peuplement. De légères applications annuelles d'engrais P, K et S corrigeront les carences et produiront un rendement plus élevé et plus consistant que de plus grandes applications conçues pour durer plusieurs années.

La production de prairie fourragère artificielle peut avoir un effet direct sur la performance des animaux. En effet, la fertilisation des prairies fourragères se caractérise par un gain du poids et une augmentation du chargement chez les animaux lorsque comparée aux prairies n'ayant reçues aucun engrais.

L'acidification du sol peut apparaître lorsque l'on applique du fertilisant sur les peuplements fourragers. Cette acidification est particulièrement causée par l'apport d'azote au sol. et est surtout importante en superficie (0-5 cm) où l'acidité et l'aluminium extractible augmentent avec la concentration d'azote. Le nitrate d'ammonium est plus acidifiant que l'urée, alors que le sulfate d'ammonium est le fertilisant azoté le plus acidifiant. Une seule application de chaux peut neutraliser effectivement l'excès d'acidité et améliorer le rendement du fourrage pour plusieurs années.

L'analyse du sol est un outil efficace pour évaluer la fertilité, les carences nutritionnelles, les problèmes de salinité et d'acidité et pour déterminer les besoins en fertilisants. De plus, le type de sol et le climat ont une influence marquée sur la manière dont le fourrage réagi à l'application d'engrais. Les recommendations sur la façon d'appliquer le fertilisant sont soumises aux variations agro-climatiques et au type de fourrage.

INTRODUCTION

The current importance of forages in Alberta is demonstrated by the fact that approximately 50% of the agricultural land base produces forages (Table 1) and forages are the major source of food for beef cattle, dairy cattle, sheep, horses, and ruminant wild life. Furthermore, sales from domestic ruminant livestock generate over 40% of total on-farm income for Alberta farmers.

Table 1. Forage land area in Alberta.

Types of forages	Hectares (1,000's)
Unimproved pasture	6,674
Improved pasture	1,742
Perennial hay and silage	1,723
Annual hay and silage	741
Seed	93
Total forage land	**10,273**
Total agricultural land	**20,811**

Source: Statistics Canada 1991 Census (numbers do not include Crown lands).

Forages are also an important component of many sustainable agriculture cropping systems in Alberta. Well managed forage crops can significantly reduce wind and water erosion on land and can also help to improve soil tilth and fertility.

Despite the importance of forage crops for livestock production and the on-going maintenance of the agricultural soil resource, forage crops are often managed poorly. A strong, productive forage stand that will last for several years is the desired objective of most producers. To maintain strong annual crop production, fertilizer nutrients must be applied regularly. However, surveys have shown that less than 25% of the improved pasture and hay land in Alberta receives fertilizer nutrient applications. Therefore, it would appear that there is considerable room for improvement in forage production with the effective use of fertilizer nutrients.

PURPOSE

Forage crops, like most other agricultural crops grown in Alberta, respond well to the application of fertilizer nutrients when soils are deficient in those nutrients. Research has shown that properly fertilized forage crops, grown under a wide range of climatic conditions, will produce higher yields of more nutritious forage than unfertilized crops will. Improved production of forage crops through better use of fertilizers requires a greater understanding of some basic interactions between soil, climate, and the forage crop.

The purpose of this publication is to provide fertilizer management information for improved production of quality hay and pasture. Nutrient requirements and soil deficiencies are discussed for grasses, legumes, and grass-legume mixtures. Research information is summarized to demonstrate how fertilizers can be applied effectively to improve forage yield and quality. Different fertilizer materials, and times, rates and methods of fertilizer applications are discussed and evaluated. Some information is also given regarding soil acidity and liming, forage quality, and economics.

FORAGE NUTRIENTS

Nutrient Requirement and Removal

Forages require 16 or more essential nutrient elements from soil for normal healthy growth (nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, copper, zinc, iron, manganese, boron, sodium, molybdenum, chloride, cobalt, vanadium and silicon). The amounts of these nutrients vary considerably among forage species. Nutrient requirements are quite different for forages compared to annual cereal grains.

In Alberta, one or more of the four main nutrients may be limiting for maximum forage production; N and P are the most commonly deficient nutrients, while K and S may also be deficient for certain crop and soil conditions. Deficiencies of other nutrients have seldom been identified in forage crops in Alberta, but more research is needed.

Large amounts of N, P, K and S are required for high forage yields (Table 2). When forages are harvested as hay or silage, these amounts of nutrients are removed from the field and these nutrients are not returned to the soil unless manure is reapplied to each field from which the forage was removed. This differs from cereal grain production where lesser amounts of nutrients are generally required and only the grain portion of the crop is removed from the field. Variations in crop nutrient requirements between forages and cereals are greatest for N and K. Requirements for these nutrients are higher for forages than for cereals and highest for legume forages.

Table 2. Plant nutrients used by three types of forage crops compared to barley grain (kg/ha).

Crop	Yield (t/ha)	N	P	K	S
Grass hay	6.7	125	15	130	10
Legume hay	9.0	270	20	180	20
Cereal silage	6.7	120	13	100	10
Cereal grain (barley)	4.3	90	15	25	15

Source: Plant Nutrients Use by Crops. Compiled by Western Canada Fertilizer Association, October, 1978.

Without adequate fertilizer, three to five years of continuous forage production can deplete soil nutrient reserves and cause a soil nutrient deficiency more quickly than continuous annual grain production. The lack of tillage when perennial forages are grown also slows the rate of nutrient release from the soil. With the exception of N for legume forages, fertilizer nutrients required for forage production generally need to be applied at higher rates than for grain production.

Fertilizer Nutrients and Climate

Nutrients contained in fertilizers are applied to make up the deficiency between the nutrients needed for optimum forage growth and the nutrients available from the soil. Although the soil can supply most of the nutrients needed for optimum growth, N and P are usually lacking. Forage yield is always reduced when soil nutrients are lacking.

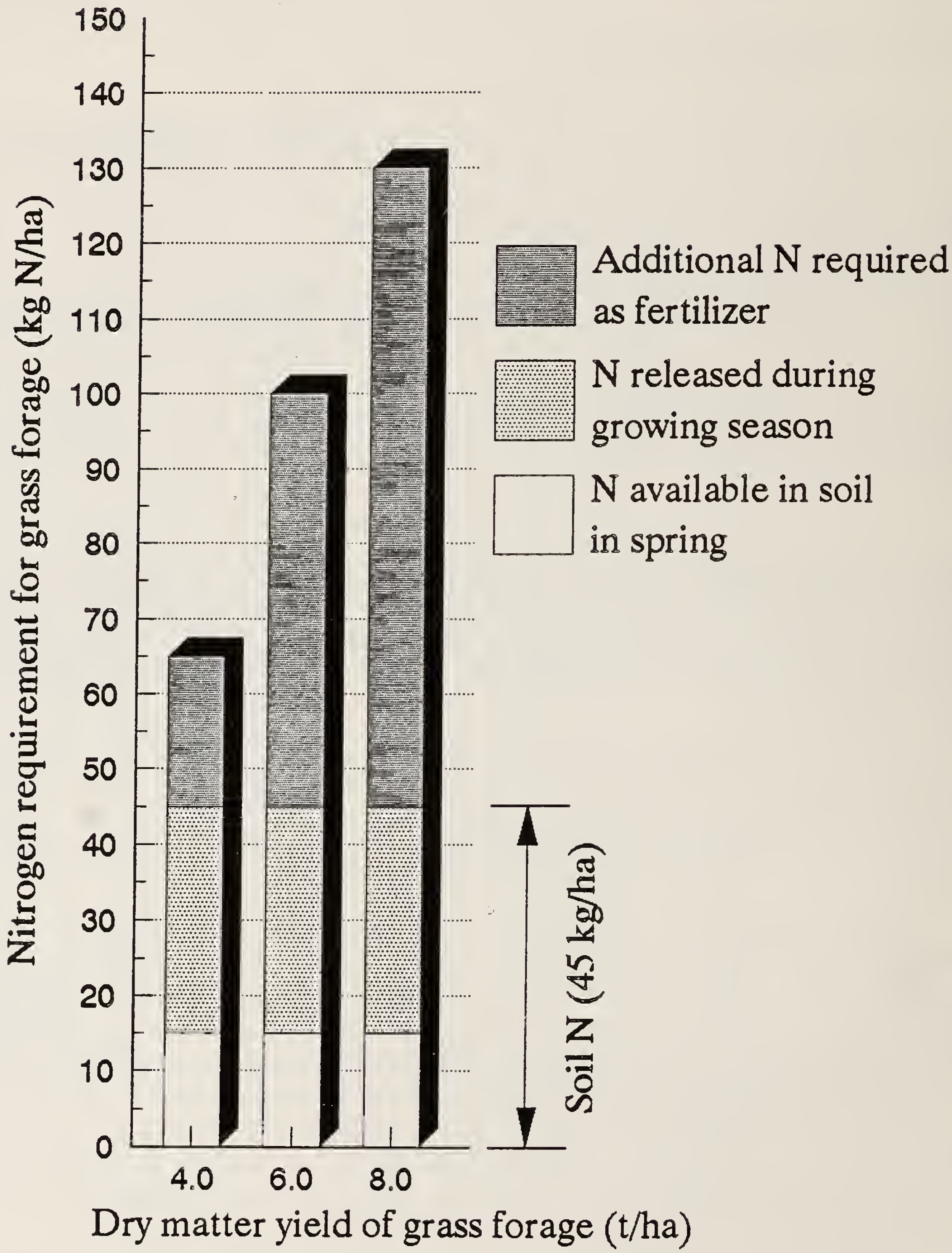
Large amounts of N are needed by forage crops to produce maximum growth. As grass forage yields increase, greater amounts of N are required. The importance of N fertilizer for balancing N requirements is apparent when the amounts of N needed for increased forage yields are compared to N released from the soil (Figure 1). The N released from the soil is small in relation to the amount of N needed for maximum forage production. If the difference between plant needs and soil supply is recognized and balanced with fertilizer N, the maximum growth potential can be achieved.

As in the case of N, the needs of a forage crop for P, K and S must be balanced with fertilizers to meet maximum crop yield when the soil supply is deficient in these nutrients. Also, when more than one nutrient is deficient in soil and only one is supplied by fertilization, crop yield will still be limited by the nutrient not provided. For example, if both N and S are deficient in the soil, adding only N or only S will not produce the full yield response that would result from the addition of both N and S.

Although N is required in large quantities by forages, only those crops with high percentage of grasses need N fertilizer. Legume forage crops can obtain most of their N requirements directly from the air through a process called N fixation. Nitrogen fixation is discussed in more detail in the section, "Legume Forage for Hay".

Adequate moisture is a critical factor affecting forage crop production, nutrient requirements, and the effectiveness of fertilizer application. Forage crop response to fertilizer application is directly related to the amounts and distribution of growing season precipitation and the ability of the soil to store water. In the drier areas of the province and on some sandy soils, response from fertilizers will be quite low because of limited available water. Fertilizers applied on established forages need to be leached into the soil before they can be used by the forage. Therefore, information regarding times and methods of application that will increase movement of fertilizer to crop roots is important to improve forage response to fertilizer. Even in the wetter areas of the province, variations in the amounts and times of seasonal precipitation can cause erratic responses to fertilizer application. However, in both dry and wet areas, strong

Figure 1. Nitrogen required for various yields of grass forage



responses occur when fertilizers are applied on nutrient-deficient soils. Residual effect of fertilizers can last for three or more years after the year of application. For these reasons, economic returns from forage fertilization need to be measured over a period of several years.

FORAGE YIELD RESPONSE TO APPLIED FERTILIZER

Three factors must be considered when determining what rate and kind of fertilizer to use on forage crops. These factors include:

- which nutrients are deficient and how severe are the deficiencies;
- what are the yield responses when various rates of fertilizer nutrients are applied; and
- what are the net returns from increased yield when crop prices, and fertilizer and application costs are taken into consideration.

The more accurately these three factors can be determined, the greater the potential for profitable returns from forage fertilization. Methods of estimating nutrient requirements and crop yield response are discussed separately for grass, legume and mixed grass-legume forages.

Grass Forage for Hay

Perennial grass forage has a high N requirement and will respond very well to fertilizer N particularly in the moist regions of Alberta. Responses to P, K and S fertilizers are more moderate and variable on most soils. Dramatic responses can occur, however, where soils are very deficient in only one of these nutrients.

Effect of N fertilizers

Grass forage crops obtain N from two main sources: (1) available N stored in the soil and mineralized during the growing season (released from soil organic matter, manure, and crop residues), and (2) fertilizer N. Nitrogen released from the soil is generally not sufficient to produce high yields of forage. Mineralization of soil N is slow in established forage stands. Only about one-quarter of the total N required for high yielding forages can be supplied from soil N during the early growing season. Soil tests of available soil N on established grass fields have shown that very little N is carried over from one growing season to the next. It appears that under forage cropping conditions, almost all available N released from soil organic reserves during the growing season is consumed immediately by the forage stand for production of new growth. Thus, there is no build up of available soil N for initial spring growth as may be expected under annual cropping conditions. Therefore, the N supplied by fertilizer becomes very important for achieving maximum yield of grass forage. Rates, sources, times and methods of N fertilizer application are factors that have a strong influence on how effectively forage crops respond and use the N fertilizer that is applied.

Rate of N application

Field research in central Alberta has shown that grass forage yields will increase with increasing rates of early spring applied N (Table 3). Although average dry matter yield (DMY) varied considerably where no N fertilizer was applied, yield consistently increased with N application for all three areas in central Alberta. With moderate rates of 100 kg N/ha, DMY increased by 2.74, 3.68 and 4.07 t/ha, respectively, for north-central, central, and south-central areas.

Table 3. Dry matter yield and protein content of bromegrass hay, fertilized annually in the spring of the year with six or seven levels of ammonium nitrate at locations in north-central, central and south-central Alberta totalling 41 site years.

Locations in Alberta	Parameters	Levels of applied N (kg N/ha)						
		0	50	100	150	200	300	
North-central	DMY§	1.37	2.99	4.11	5.16	5.82	7.09	
(Ave. 3 yr - 2	PC†	12.5	10.3	12.1	13.7	14.6	16.3	
locations)	PY‡	171	308	497	707	850	1156	
Central	DMY	3.86	5.98	7.54	8.49	8.70	8.73	
(Ave. 4 yr - 4	PC	11.2	11.6	13.0	14.4	15.2	15.8	
locations)	PY	432	694	980	1223	1322	1379	
		Levels of applied N (kg N/ha)						
		0	56	112	168	224	280	336
South-central	DMY	1.17	3.63	5.24	5.41	5.69	5.62	5.45
(Ave. 19 yr - 1	PC	7.3	7.2	8.5	9.6	11.0	10.9	11.6
location)	PY	84	247	425	496	582	576	598

§DMY = dry matter yield (t/ha).
†PC = protein content (%).
‡PY = protein yield (kg/ha).

Protein content in forage is important to livestock nutrition. As the rate of N increased, protein content increased up to the maximum rate of N applied (Table 3). At the lower rates of N (*i.e.* 50 and 100 kg N/ha) where DMY response to N was greatest, the increase in protein content from N application was the smallest. At high N rates the DMY response decreases and protein content in the forage increases more rapidly. This is understandable since N is required for plant growth and where DMY is small, N will accumulate as extra protein. High DMY and protein content will occur at N rates that approach maximum yield. Protein yield (PY), which is the result of DMY and protein content, also increases with increasing rates of applied N, but at a faster rate. Thus, more protein will be produced per hectare at an N rate of 150 kg N/ha than at 100 kg N/ha because both DMY and protein content are greater.

Single initial vs annual N applications

Often a high initial N application is suggested on the assumption it will last for several years of grass forage production. Such a practice would reduce labor costs and might allow producers to take advantage of favorable fertilizer prices and years with above-average rainfall. Studies in central and north-central Alberta compared high single N application with smaller annual applications for 3 to 4 years. Single initial application produced the greatest effect on DMY in the first year, but the effect did not persist beyond the third year and yields dropped significantly after the second year (Table 4).

When individual treatments were summed and averaged for the 3 or 4 years of the studies, it was possible to compare the responses to equal rates of N (e.g. 50 kg N/ha annually for 3 years vs 150 kg N/ha single initial). In the north-central and central Alberta trials, annual applications generally produced greater DMY and PY than single initial application (Table 5). These results indicate that smaller annual N applications will produce higher and more consistent yields of dry matter than will equivalent single N application made every three or four years.

Annual single vs split N applications

Grass forage gives a strong yield response to early spring applied N. Split N application during the growing season has been successfully used in areas where two or more cuts of hay are regularly harvested. In drier areas of the province, where total yields of forage are relatively low and only one cut of hay is usually harvested, splitting the N application during the growing season is not recommended. In many areas of Alberta, the growing season rainfall is irregular and unpredictable, particularly in July and August. So, split N application gives variable results. In areas with higher rainfall or with irrigation and where two or more cuts of hay are regularly harvested, applying N in two or more increments may be beneficial.

Source and time of N application

Several N sources are available for forage fertilization and the majority of forage fertilization is done with granular fertilizer . The N source for granular fertilizer is heavily dominated by urea. Nitrogen fertilizers are usually applied to forage stands in early spring. Farm workload and weather conditions may cause producers to consider other times of N application. Experiments conducted in south-central Alberta have shown that some application times and N sources produce more consistent DMY and PY responses than other times and sources (Table 6). In this study, DMY was measured over a period of 15 years at four locations in response to annual applications of 112 kg N/ha using two N sources, ammonium nitrate and urea, at two dates in the fall and two dates in the spring. Strong DMY increases occurred at all locations from both fall and spring applications for each N source. For all dates of applications, urea produced lower DMY increases than ammonium nitrate. Average DMY for fall and spring applied N were consistently higher for ammonium nitrate compared to those for urea (4.36 *vs* 3.82 t/ha for fall

Table 4. Total dry matter yield of smooth bromegrass managed as hay, treated with three rates of a single application of ammonium nitrate during the initial year at four locations in central Alberta and two locations in north-central Alberta.

Locations	Year	Levels of applied N (kg N/ha)		
		0	200	400
		t/ha		
Lacombe	1975§	9.52	10.66	9.92
	1976	5.78	9.51	11.71
	1977	2.85	2.97	4.54
	1978	3.56	4.36	3.11
	1979	3.12	3.53	3.12
Joffre	1975§	7.16	7.79	8.78
	1976	3.13	5.54	7.09
	1977	2.88	3.97	6.32
	1978	4.51	5.52	6.15
	1979	2.97	2.90	2.96
Botha	1975§	4.75	6.76	7.93
	1976	2.34	3.37	4.96
	1977	2.15	2.43	3.13
	1978	4.23	3.94	6.61
	1979	3.36	2.92	3.93
Rocky	1976§	8.77	15.36	13.76
Mountain	1977	4.09	5.72	10.66
House	1978	4.86	5.45	5.27
	1979	3.12	4.01	4.16
		Levels of applied N (kg N/ha)		
		0	150	300
Ellerslie	1975§	0.89	4.28	4.88
	1976	0.26	0.53	2.33
	1977	0.69	0.72	0.69
Vimy	1976§	1.73	4.76	6.64
	1977	2.18	3.14	4.11
	1978	2.47	3.10	2.12

§ Year of application.

Table 5. Dry matter yield of smooth bromegrass hay (t/ha) summed over three or four years and averaged for N fertilizer in single initial or annual applications at locations in north-central and central Alberta.

Locations in Alberta	Level of applied N fertilizer (kg N/ha)				
	0	Single 150	Annual 3 x 50	Single 300	Annual 3 x 100
North-central (3 yr - 2 locations)	4.11	8.27	8.97	10.39	12.33
	Level of applied N fertilizer (kg N/ha)				
	0	Single 200	Annual 4 x 50	Single 400	Annual 4 x 100
Central (4 yr - 4 locations)	18.43	24.34	27.04	28.53	32.09

and 4.40 *vs* 3.98 t/ha for spring). Early spring applied N gave the highest DMY for both urea and ammonium nitrate. The lowest yield response for urea occurred when applied in early fall, while for ammonium nitrate the lowest yield response occurred when applied in the late spring.

Urea was a less effective N source for increasing protein yield and content than ammonium nitrate (Table 6). Average protein yields were 445, 376 and 167 kg/ha, respectively, for ammonium nitrate, urea, and no fertilizer N treatments. In the same order, average protein contents were 10.4, 9.9 and 8.7%. Ammonium nitrate gave protein contents that were similar for fall and early spring applications. However, for urea, fall applications resulted in lower forage protein contents than when applied in spring. Late spring application gave the highest protein yield and content for both N sources. The higher protein yield with late spring application than early spring application suggests that the applied N became available to plants later in the growing season. The N use efficiency and % N recovery were lower when urea was the N source compared to ammonium nitrate at all dates of application (Table 6). The percent recovery of applied N was greatest when N was applied in the late spring and early fall application gave the lowest N recovery.

In another study in north-central Alberta, N sources were compared when two rates of N were applied in early spring on established bromegrass (Table 7). Dry matter yield increased markedly with N applications in this study. Ammonium nitrate was slightly superior to urea in increasing dry matter yield, protein yield, protein content, N use efficiency, and recovery of applied N at application rates of 50 and 100 kg N/ha.

In summary, ammonium nitrate produced greater dry matter and protein yield than urea. This is likely due to the well established fact that urea is more vulnerable to ammonia volatilization loss than similarly applied ammonium nitrate. Although, ammonium nitrate outperforms urea, it must be emphasized that urea is still a good source of N for forage crops when considering its cost and availability.

Table 6. Dry matter yield (DMY), protein yield (PY), protein content (PC), N use efficiency (NUE), and recovery of applied N (NR) with bromegrass managed as hay and treated annually with urea and ammonium nitrate fertilizer at 112 kg N/ha in early fall, late fall, early spring and late spring for 15 years at four locations in south-central Alberta.

		Time of application and source							
		Early fall		Late fall		Early spring		Late spring	
	Check	A.N.§	Urea	A.N.	Urea	A.N.	Urea	A.N.	Urea
DMY (t/ha)	2.06	4.39	3.80	4.32	3.85	4.53	3.98	4.26	3.98
PY (kg/ha)	167	430	335	422	347	454	392	474	429
PC (%)	8.7	10.1	9.1	9.9	9.3	10.2	10.0	11.3	11.0
NUE (kg DM/ha/kg N)		21.3	15.9	21.0	16.5	22.6	17.7	20.0	17.4
NR (%)		38.0	24.3	37.1	26.4	41.8	32.4	44.0	37.6

§ A.N. - Ammonium nitrate.

Table 7. Dry matter yield (DMY), protein yield (PY), protein content (PC), N use efficiency (NUE), and recovery of applied N (NR) with smooth bromegrass managed as hay and fertilized annually with ammonium nitrate and urea at 50 and 100 kg N/ha applied in early spring for three years at two locations in north-central Alberta.

		N rate and source			
		50 kg N/ha		100 kg N/ha	
	Check	A.N.§	Urea	A.N.	Urea
DMY (t/ha)	1.37	2.99	2.79	4.11	3.81
PY (kg/ha)	171	308	286	497	441
PC (%)	12.6	10.3	10.3	12.1	11.6
NUE (kg DM/ha/kg N)		32.3	28.4	27.4	24.4
NR (%)		43.5	36.6	52.0	43.0

§ Ammonium nitrate.

Effect of P fertilizer

Unlike nitrate-N (NO_3-N) and sulphate-S (SO_4-S) which move relatively freely with water in the soil, P is quite immobile. For this reason, placement of P fertilizer in the soil where it will be directly intercepted by roots is very important. To place the P below the soil surface in established forage stands has been difficult and often impractical due to the stand damage that can result from attempting this practice. Hence, for P-deficient soils, P fertilizer is usually broadcast and incorporated at high rates prior to forage establishment, and/or broadcast on the soil surface for established stands.

A field experiment was conducted over a five-year period to compare the effects of prior P incorporation with annual P applications in central Alberta using smooth bromegrass as the test crop (Tables 8 and 9). Rates for annual spring broadcast P application were 0, 10, 20, 30, 40, and 60 kg P/ha (Table 8). Single initial P application rates of 60, 120, and 180 kg P/ha were broadcast and incorporated in the soil just prior to seeding bromegrass (Table 9). On this P-deficient soil, the greatest DMY increase resulted from the first 10 kg P/ha, but DMY continued to increase up to the 60 kg P/ha rate. The reported results also show that single initial application as low as 60 kg P/ha produced increase in DMY in the fifth year. This would indicate that P broadcast and incorporated in the soil prior to the establishment of grass forage will remain available to the crop for several years.

In this same study, two cuttings of hay were harvested in four of the five years that results were collected. In all years, P fertilizer application increased the DMY of the second cut for all rates of P application. At the 60 kg P/ha rate, the average DMY for the second cut was 1.35 t/ha higher than where no P was applied. This indicates that a good supply of available P in the soil will contribute to stronger plant growth throughout the growing season. Thus, by simply applying moderate annual rates of P early in spring, marked increases in late season DMY can be obtained. This would be most significant for pasture and for hay in areas where consistent second cut hay harvests are possible.

Table 8. Dry matter yield (t/ha) of first and second cuts of smooth bromegrass hay, treated annually with six levels of phosphorus for four years at Lacombe in central Alberta.

		Levels of applied P (kg P/ha)					
Year	Cut	0	10	20	30	40	60
1976	1	7.75	8.80	7.99	8.96	8.83	8.62
	2	3.04	3.81	4.31	4.62	4.50	4.83
	Total	10.79	12.61	12.30	13.58	13.33	13.45
1977	1	6.82	7.29	7.64	7.56	7.77	7.88
	2	2.57	3.42	3.41	3.38	3.49	3.94
	Total	9.39	10.71	11.05	10.94	11.26	11.82
1978	1	7.25	7.83	8.26	7.88	7.59	8.54
	2	0.82	1.77	1.54	1.72	2.03	2.31
	Total	8.07	9.60	9.80	9.60	9.62	10.85
1979	1	5.25	6.60	6.98	6.84	6.46	7.20
	2	1.44	2.00	2.23	2.00	2.07	2.20
	Total	6.69	8.60	9.21	8.84	8.53	9.40
Mean	1	6.77	7.63	7.72	7.81	7.66	8.06
(1976-79)	2	1.97	2.75	2.87	3.08	3.02	3.32
	Total	8.74	10.38	10.59	10.89	10.68	11.38

Table 9. Total dry matter yield (t/ha) of smooth bromegrass hay, treated with four levels of phosphorus incorporated into soil in the establishment year (1974) and harvested from 1975 until 1979 at Lacombe in central Alberta.

	Levels of applied P (kg P/ha)			
Year	0	60	120	180
1975	10.06	11.47	11.02	12.24
1976	10.79	11.66	13.42	12.38
1977	9.39	10.42	10.87	10.32
1978	8.07	10.90	9.72	9.25
1979	6.69	7.74	7.82	7.74
Mean (1975-79)	9.00	10.44	10.57	10.39

To determine the amount of P fertilizer that moved into the soil profile, extractable P was measured in soil samples taken from experimental sites where P had been surface broadcast on established forage for several years. On a sandy loam soil at Lacombe, annual P applications on a creeping red fescue stand for seven years totalled 67 to 536 kg P/ha. At the end of this period, extractable P in soil samples taken from the 0-5, 5-15, 15-30 cm depth showed that the majority of fertilizer P recovered as extractable P was present in the 0-5 cm depth (Table 10). There was some increase in extractable P in the 5-15 and 15-30 cm depths,

but only at the two highest rates of P application. At the two lowest rates, little of the applied P moved below the 5 cm depth. Similar results were found in other experiments on different soils showing that most of the applied P remained near the surface and greater P movement in the soil occurred with higher rates of application and on the coarse textured soils. Although some fertilizer P moves into the upper part of the soil, most remains very near the surface and this P will be available to plants only as long as the surface soil is moist and roots are active in the zone of P concentration.

Table 10. Extractable P in soil after application of P fertilizer to creeping red fescue over seven years on a Black chernozem soil at Lacombe in central Alberta.

P applied in seven years (kg P/ha)	Extractable P in soil (ppm)†		
	0-5 cm	5-15 cm	15-30 cm
0	17	10	6
67	48	12	9
134	87	13	8
268	145	25	10
536	258	72	19

† Miller and Axley extractable P (parts per million).

Effects of K and S fertilizers

Like P, the need for applying K or S on grass forage is not as great as is the need for N fertilizer. However, on deficient soils, these nutrients must be applied in order to obtain high yields of forage grass. Regular soil tests are the best means of determining if K and S are likely to be limiting for forage production. Large amounts of nutrients are used by grass forage and as these nutrients are removed from the field in harvested product, the available supplies of P, K and S in the soil may be rapidly reduced. Thus, nutrients may become deficient after 2 or 3 years of forage production on fields where the soil tests showed nutrient supplies to be marginal to adequate at the time of forage establishment.

Deficiencies of P, K and S have also been associated with reduced forage quality, particularly protein content. More research is needed to establish this relationship for grass forage.

Economics of N fertilizers

Grass forages such as smooth bromegrass respond well to N fertilizer application on most soils in central Alberta. Dry matter yield, however, varies considerably with annual weather fluctuations between different soil zones and with different soil types. The economics of forage fertilization will, therefore, also vary with climate and soil differences as well as with the price of hay and fertilizer N. Results from field experiments have been used to calculate the returns above fertilizer costs and the most economical rates of N on the basis of soil-climate

zone, hay price and N fertilizer cost.

One study involved two locations in central Alberta (Lacombe, and Rocky Mountain House) and one location in east-central Alberta (Botha) over four years and with six annual rates (0 to 300 kg N/ha) of ammonium nitrate fertilizer applied to bromegrass. A close relationship was found, at each location, between total dry matter yield (TDMY) and the rate of annually appplied N. The TDMY increased more slowly as the rate of N fertilizer increased (Table 11). The TDMY response to fertilizer N varied with the location, Lacombe showing the highest and Botha showing the lowest increase. Botha was a relatively dry area and therefore produced lower TDMY than the other locations which were in relatively wetter areas.

The economic returns above fertilizer costs changed with location and were influenced by TDMY, yield response to applied N, cost of N fertilizer, and the value of hay (Table 11). Returns above fertilizer costs increased with increasing rates of N fertilizer, with the maximum occuring at the most economical N rate and decreasing thereafter. At $60/t of hay and $500/t of N, maximum returns above fertilizer costs were $375, $166 and $98/ha at N rates of 200, 150 and 100 kg N/ha, respectively, at Lacombe, Rocky Mountain House and Botha. Lower net returns at Botha were due to the low rainfall common to the area. Differences among the other locations were due to soil type.

In another experiment in south-central Alberta, seven levels (0-336 kg N/ha) of ammonium nitrate were applied early in the spring for 19 years on established bromegrass at one location. The DMY increased with N application to a maximum at 224 kg N/ha. The increase in DMY per unit N from fertilization, however, was greatest with rates of 56 and 112 kg N/ha. The economic returns above fertilizer costs maximized at N rates close to 112 kg N/ha.

Many central Alberta producers apply only 30 to 60 kg N/ha when they are fertilizing hay and pasture fields. These N levels are considerably lower than the most economical rates of N fertilizer calculated for even the drier areas and years in these long-term studies. Often a wider risk or uncertainty factor, such as 1.5 to 2.0, is desired for capital input for hay production. Table 12 shows the dollar returns per dollar invested on N fertilizer for the locations studied in central, east-central and south-central Alberta. More intensive N fertilization can be economically practised, particularly in the moister areas in central Alberta. In addition to the increase in DMY resulting from N fertilization, it must also be recognized that there is an increase in protein content and improved soil tilth.

Legume Forage for Hay

High yielding legume crops that may produce two to three cuts per year remove large amounts of the four major plant nutrients (N, P, K, S). Compared to cereal grain crops, legumes may remove three times as much N and K and two times as much P and S (Table 12). These large nutrient removals by legume crops make it essential to monitor the soil fertility status and forage nutrient composition annually in order to manage fertilizer inputs for maximum economic production of quality legume forage.

Table 11. Returns above fertilizer costs with N applications to smooth bromegrass grown as hay over a period of four years at Lacombe and Rocky Mountain House in central Alberta and Botha in east-central Alberta, and 19 years at Crossfield in south-central Alberta at selected hay and fertilizer prices.

		DMY increase	Net returns ($/ha)								
	Rate of N	from applied	$400/t of N			$500/t of N			$600/t of N		
Location	(kg N/ha)	N (t/ha)	40§	60	80	40	60	80	40	60	80
Lacombe	50	2.42	77	125	174	72	120	169	67	115	164
	100	4.42	137	225	314	127	215	304	117	205	294
	150	6.81	212	349	485	197	334	470	182	319	455
	200	7.91	236	395	553	216	375	533	196	355	513
	300	8.19	208	371	535	178	341	505	148	311	475
Rocky	50	1.77	51	86	122	56	81	117	41	76	112
Mountain	100	3.42	97	165	234	87	155	224	77	145	214
House	150	4.02	101	181	262	86	166	247	71	151	232
	200	3.97	79	158	238	59	138	218	39	118	198
	300	4.27	51	136	222	21	106	192	-9	76	162
Botha	50	1.90	56	94	132	51	89	127	46	84	122
	100	2.47	59	108	158	39	98	148	39	88	138
	150	2.03	21	62	102	6	47	87	-9	32	72
	200	2.14	6	48	91	-14	28	71	-34	8	51
	300	2.02	-39	1	42	-69	-29	12	-99	-59	18
Crossfield	56	2.46	76	125	174	70	120	169	65	114	163
	112	4.07	118	199	281	107	188	270	96	177	258
	168	4.24	102	187	272	86	170	255	69	154	238
	224	4.52	92	182	272	69	159	250	46	137	227
	280	4.45	66	155	244	38	127	216	10	99	188
	336	4.28	37	122	208	3	89	174	-30	55	141

§ Hay price in $/t.

Table 12. Returns per dollar invested on fertilizer N for smooth bromegrass grown as hay at selected hay and fertilizer prices.

Location (part of Alberta)	Rate of N (kg N/ha)	DMY from applied N (t/ha)	Returns per dollar invested on fertilized N (benefit to cost ratio) ($400/t of N)			$500/t of N			$600/t of N		
			40§	60	80	40	60	80	40	60	80
Lacombe (Central)	50	2.42	3.85	6.25	8.70	2.88	4.80	6.76	2.22	3.84	5.45
	100	4.42	3.43	5.62	7.85	2.54	4.30	6.08	19.5	3.42	4.89
	150	6.81	3.53	5.82	8.08	2.63	4.45	6.27	2.03	3.54	5.05
	200	7.91	2.95	4.94	6.91	2.16	3.75	5.33	1.64	2.95	4.27
	300	8.19	1.73	3.09	4.46	1.19	2.27	3.37	0.82	1.73	2.64
Rocky Mountain House (Central)	50	1.77	2.55	4.30	6.10	2.24	3.24	4.68	1.36	2.54	3.72
	100	3.42	2.43	4.13	5.85	1.74	3.10	4.48	1.28	2.42	3.56
	150	4.02	1.68	3.02	4.36	1.15	2.21	3.29	0.79	1.48	2.57
	200	3.97	0.99	1.98	2.98	0.59	1.38	2.18	0.32	0.98	1.65
	300	4.27	0.43	1.13	1.85	0.14	0.71	1.28	-0.05	0.42	0.90
Botha (East-central)	50	1.90	2.80	4.70	6.60	2.04	3.56	5.08	1.53	2.80	4.06
	100	2.47	1.48	2.70	3.95	0.78	1.96	2.96	0.65	1.47	2.29
	150	2.03	0.35	1.03	1.70	0.08	0.63	1.16	-0.10	0.35	0.80
	200	2.14	0.08	0.60	1.14	-0.14	0.28	0.71	-0.29	0.07	0.43
	300	2.02	-0.33	0.01	0.35	-0.46	-0.19	0.08	-0.55	-0.33	0.10
Crossfield (South-central)	56	2.46	3.39	5.58	7.77	2.50	4.29	6.04	1.93	3.39	4.86
	112	4.07	2.63	4.44	6.27	1.91	3.36	4.82	1.42	2.63	3.85
	168	4.24	1.52	2.78	4.05	1.02	2.02	3.04	0.68	1.52	2.37
	224	4.52	1.03	2.03	3.04	0.62	1.42	2.23	0.35	1.02	1.69
	280	4.45	0.59	1.38	2.18	0.27	0.91	1.54	0.06	0.59	1.12
	336	4.28	0.28	0.91	1.55	0.02	0.53	1.04	-0.15	0.27	0.70

§Hay price in $/t.

Effect of N fertilizer and N-fixing bacteria

Alfalfa, like other legume crops, co-exists with nodulating bacteria that can take large quantities of N from the atmosphere and change it to a form that is available to plants. Consequently, no N fertilizer is required for properly inoculated legume forages which are utilizing atmospheric N. Large amounts of N fertilizer may cause the nodulating bacteria to reduce fixing of atmospheric N.

Adequate soil fertility and the proper inoculation of legume seed with specific bacteria suited to the legume crop are critical factors for transfer of sufficient N from the bacteria to the growing legume. For more details regarding legume bacteria and how to inoculate legumes, the reader is referred to Agdex No. 100/23-1, "Inoculation of Legume Crops", available from Alberta Agriculture. Legumes should be checked occasionally for the presence of effective nodules on the roots. The presence of large nodules that are bright pink in color, when cut open, is a good indication that the legume crop is being supplied with N. Legume bacteria are growing organisms that require nutrients to function. When soils are deficient in nutrients, the bacteria function less effectively in fixing and transferring N to the plant. Sulphur deficiency is the most common nutrient limiting the activity of these bacteria. Soil pH is also important. Nodule formation and functioning is severely limited by acid soil conditions (pH < 6.0).

Effect of P fertilizer

Phosphorus is commonly deficient in Alberta soils. Therefore, annual applications of P are usually required to maintain high legume yields. Generally, legume forages will produce higher yields and use P more effectively with annual applications of P than from a single large application made at seeding that is intended to last for several years of production. On very P-deficient soils, the full benefit of annual applications of P may not be realized for two to three years. Therefore, it is important to apply P fertilizer prior to seeding for establishing legume stands, followed by annual applications of P.

Field experiments have been conducted to determine legume response to P fertilizer when applied annually compared to single initial application broadcast and incorporated prior to establishment (Tables 13, 14 and 15). Response varied between the two locations, partly due to climatic conditions and level of available P in the soil. Lacombe, located in a higher rainfall area, had a greater DMY potential. However, the available P in the soil was relatively low (Table 13). At the drier site (Botha), soil available P was medium. Average alfalfa DMY increased at both locations with P application. On the soil where available P was low and moisture was adequate (Lacombe), average alfalfa DMY was increased by 1.73 t/ha with an annual application of only 10 kg P/ha. Similarly, at the 20 kg P/ha rate, average DMY increased by 2.97 t/ha. Average DMY increases at the drier location with a medium soil available P supply were smaller but consistently showed a response to applied P in dry and wet years.

Results of first and second cut of alfalfa DMY taken at Site 1 are reported in Table 14. Yield of both first and second cuts of alfalfa increased with P application. At the rate of

Table 13. Average total dry matter yield (t/ha) with six rates of P fertilizer applied annually to alfalfa forage managed as hay for three or four years at two locations in central Alberta.

Site	Soil test P (kg P/ha)	Rate of applied P (kg P/ha) 0	10	20	30	40	60
Lacombe (3 yrs)	18	4.53	6.26	7.50	7.47	7.64	7.65
Botha (4 yrs)	27	4.07	4.32	4.73	4.98	5.55	4.89

Table 14. Average dry matter yield (t/ha) of first and second cuts of alfalfa forage managed as hay with six rates of P fertilizer applied annually for three years at Lacombe in central Alberta.

Cut No.	Soil test P (kg P/ha)	Rate of applied P (kg P/ha) 0	10	20	30	40	60
1	18	3.21	4.24	4.72	4.91	4.80	4.86
2		1.32	2.02	2.78	2.56	2.84	2.79

Table 15. Average total dry matter yield (t/ha) with four rates of P fertilizer broadcast and incorporated in a single initial application prior to establishment of alfalfa managed as hay for three or four years at two locations in central Alberta.

Site	Soil test P (kg P/ha)	Rate of applied P (kg P/ha) 0	60	120	180
Lacombe (3 yrs)	18	4.53	6.86	7.78	7.58
Botha (4 yrs)	27	4.07	4.47	5.07	5.07

20 kg P/ha, DMY for the first cut was 1.5 times greater than the DMY where no P was applied and was 2.1 times greater for the second cut. Thus, DMY of alfalfa can be increased substantially with relatively small (20 to 40 kg P/ha) annual P fertilizer applications, particularly when soils test low in available P. Also, these responses are extended later into the growing season where this may be an advantage for second cutting of hay or for extended pasture production.

Single initial application of P incorporated before alfalfa was established resulted in DMY increase from rates of 60 and 120 kg P/ha (Table 15). No further increase in average DMY resulted at the rate of 180 kg P/ha. The residual effect of large single P application lasted at least for four years but DMY diminished with time.

Phosphorus applied at low rates on the surface of forage stands may not become completely available in the year of application because sufficient P does not move downward into the soil to the rooting zone of the crop. At higher rates, more P is moved into the soil and some is carried over for use by crops in subsequent years. Some P carryover is desirable to ensure there is always an adequate supply of P to meet early growth needs. One should also recognize that at low rates of P fertilization on P-deficient soils, a large part of the plant requirement for P will be removed from the soil.

Effect of K fertilizer

Potassium is a nutrient that is used in large quantities by legumes. Although the majority of Alberta soils contain adequate K for legume production, there are some soils in the central and north-east regions that will benefit from K fertilization. Coarse textured soils (loamy sand and sandy loam) and organic soils are most likely to be K deficient. Both yield, and protein content, will be increased by the application of K on low K soils. On such soils, research has shown that an adequate supply of K will stimulate fixation of N by nodule bacteria and the regrowth of legumes following harvest. Potassium has also been shown to decrease the incidence of winter injury in legume stands because adequate K increases the accumulation of carbohydrates in the root system of legumes. On marginal and K-deficient soils, legumes may produce well in the first year of establishment or for the first cuts in subsequent years. However, after several harvests the soil K supply will not maintain high yields of legumes. Thus, under K-deficient conditions, the stand of legume is reduced and the quality of forage decreases significantly. Annual applications of K fertilizer can avoid these problems and will ensure the legume crop will be able to take full advantage of favorable climatic conditions for maximum growth.

Effect of S fertilizer

Sulphur is deficient in many soils in west-central and northern Alberta. Soils most commonly deficient in S are Gray Wooded (Gray Luvisol) and coarse textured Black and Thin Black Chernozem soils. Many years of experiments on these soils have shown that over 50% contain insufficient S for producing high yields of legume forage. Sulphur is an essential nutrient for N-fixing bacteria in legume crops. Therefore, S affects both yield and protein content of legumes. Because S deficiency reduces N fixation, S-deficient legumes are stunted, appear pale green in color and have low protein content. However, both yield and forage quality can be decreased by S deficiencies long before visual symptoms appear. On S-deficient soils, marked increases in yield and forage quality have resulted from relatively small (20 to 25 kg S/ha) annual applications of S. Soils growing legumes should be tested regularly to insure an adequate supply of S is available in the soil.

Effect of S fertilizer on selenium (Se) concentration of forage

Although Se is not needed as a plant nutrient, it is needed for animals and low Se (<200 parts per billion) levels in livestock rations have been associated with white muscle disease in beef cattle and sheep. High incidence of this disease has been found in west-central Alberta and farmers suspect S fertilizers applied on pasture and hay crops increases white muscle desease.

To determine the effect of S fertilizer on Se levels in forage, yield response trials and plant analyses were conducted on forage from 59 sites over two years. Soils were all Gray Wooded, ranging in texture from sandy loam to clay loam and in pH from 5.1 to 6.9. At 40 sites, the soil was S-deficient.

Generally, the results showed that Se concentrations in the forage grown in the test region were low (Table 16). Concentrations were less than 100 ppb (parts per billion) Se in all samples of bromegrass, alsike and red clover, and less than 20 ppb Se in timothy hay. Average Se levels for alfalfa were higher than for other species; however, two-thirds of the samples still contained less than 100 ppb Se. When S fertilizer was applied, average Se concentration decreased in all forage species. This decrease, however, was most pronounced where the S fertilizer increased forage production and where Se levels without fertilizer were greater than 100 ppb Se. Therefore, the reduction in Se content in forage seems to be caused by dilution resulting from increased forage production.

Table 16. Selenium in top growth of forage species sampled at the early flowering stage of growth in west-central Alberta.

Species	Yield response to S fertilizer	No. of samples	Selenium in top growth (ppb)§			
			Without S fertilizer		With S fertilizer	
			Ave.	Range	Ave.	Range
Alfalfa	Yes	10	242	10-1005	112	12-470
	No	13	113	10-560	79	13-217
Alsike clover	Yes	31	18	3-59	13	2-27
	No	7	24	7-68	15	6-22
Red Clover	Yes	26	19	7-56	11	4-23
	No	4	8	6-9	7	4-8
Bromegrass	Yes	7	28	12-58	22	4-33
	No	8	31	12-86	26	12-43
Timothy	Yes	19	12	4-19	11	5-26
	No	6	12	6-19	9	4-17

§ Parts per billion (10^9).

Where possible, direct comparison of Se content was made between forage species grown at the same site. Alfalfa had a much higher content than other species. This indicated that for some unidentified reason, alfalfa is able to take up more Se from soils than other common forage species. Other legumes were generally slightly higher in Se content than grasses.

These results indicate that much of the forage grown in west-central and some other areas of Alberta is deficient in Se for good animal health. Forage Se concentrations were often reduced when S fertilizer was applied, particularly on S-deficient soils. When forages are suspected of being low in Se, samples should be analyzed and mineral supplements be used in livestock ration as required.

Grass-Legume Mixtures for Hay

Managing soil fertility for mixed grass-legume forages is much more difficult than for pure grass or legume stands. It is not possible to provide an ideal combination of nutrients for both crops grown in mixed stands. If too much N is applied to a grass-legume mixture, the grass will be stimulated and become dominant and the N fixation activity of the legume nodule bacteria will be decreased. Applying adequate P, K and S fertilizers to mixed stands is important for maintenance of the legume component and may cause legumes to become dominant.

Effect of N fertilizer

In experiments at eight sites, there appears to have been a general relationship between the initial nitrate-N in the soil or the percentage of alfalfa in forage stands and the DMY response to applied N or the net returns above fertilizer costs (Table 17). If either soil test N or percent legume is high, the yield response to applied N is low. On the Black Chernozem soils, DMY without N fertilizer were quite high and DMY increases from applied N were generally small. With the exception of one site, Gray Wooded soils produced much lower DMY when not fertilized. Soil at that site had a higher organic matter content and did not appear strongly eluviated. The results also indicated that the sites with greater than 50% alfalfa in the stands produced high yields when not fertilized and were less responsive to applied N.

The economic appraisal of DMY indicated that returns above fertilizer costs were influenced by soil type, initial soil nitrate-N level and the percentage of alfalfa in forage stands. On Black Chernozem soils, there were no net returns from N application (Table 17). The net returns from applied N were greater on soils with low levels of nitrate-N. The net returns and the N rate which produced the highest DMY were lower on soils with more than 50% alfalfa in the stands. At two Gray Wooded sites which had approximately 50% alfalfa in the stands, the soils gave DMY response to applied N and produced net returns with N application up to 45 or 90 kg N/ha. The Gray Wooded soils (which are inherently low in organic matter and have low N supplying power during the growing season) gave yield responses to applied N and produced more economic returns from N application than did the mixed forage trials located on Black Chernozem soils. Soils with high initial nitrate-N and with alfalfa greater than 50% produced small yield responses and no economic benefit from N application. The results also indicated that DMY increased with applied N, but the high N rates in many instances produced low or negative net returns. This emphasizes that an evaluation of DMY response to applied N is not sufficient in itself and should be accompanied by economic appraisal.

Table 17. Dry matter yield (DMY) and returns above fertilizer costs with four or five rates of N fertilizer applied to smooth bromegrass-alfalfa mixtures managed as hay for two to five years at six locations in central Alberta.

Soil	No. of sites	Initial NO_3-N§ in soil (kg N/ha)	Length of expt. (years)	% of alfalfa	Rate of N (kg N/ha)	DMY (t/ha)	DMY increase (t/ha)	Net return ($/ha)†
Black Chernozem††	3	55	4	60	0	5.24		
					45	5.38	0.14	-11
					90	5.47	0.23	-27
					135	5.39	0.15	-56
					180	5.52	0.28	-68
Gray Wooded††	2	6	2-3	36	0	2.01		
					45	2.64	0.63	28
					90	3.13	1.12	45
					135	3.28	1.27	34
					180	3.55	1.54	33
Gray Wooded††	1	23	4	57	0	4.43		
					45	4.99	0.56	22
					90	4.97	0.54	-2
					135	5.10	0.67	-14
					180	5.60	1.17	4
Gray Wooded	2	§§	3-5	50	0	2.83		
					22.5	3.15	0.32	14
					45	3.41	0.58	24
					90	3.70	0.87	25

§Depth of soil 0-30 cm.
§§NO_3-N not determined.
†At hay price of $80/t and fertilizer price of $500/t of N.
††Source: Webster et al. 1976. Alberta Institute of Pedology Publication Number M-76-10 (for Sites 1, 2 and 3).

When managing mixed forage stands, knowledge of the legume percentage and the fertility status of the soil are most important. Generally, stands with more than 80% grass should be fertilized as pure grass and those with more than 80% legume should be treated as pure legume. A common mixture that one might attempt to maintain is 40 to 60% legume. Regular soil testing is an essential tool for decisions regarding the fertilizer nutrients required to balance and maintain a desired mixture. To maintain approximately 50% legume in the mixture and thereby receive the benefit of the N-fixing power of legume bacteria, little or no N should be applied and adequate levels of P, K and S must be maintained. Although large responses to N have been reported for mixed forages, it is the grass component that is stimulated while the legume component is sharply reduced. Furthermore, there is a risk that N fertilizer will reduce the ability of the legume component to survive and to contribute to yield in future years.

Often the legume content can be reduced to less than 25% within three or four years when relatively small (50 to 100 kg N/ha) amounts of N are applied annually. However, when P, K and S are applied on an annual basis, the legume percentage and the forage quality can be maintained at a more stable level.

Effect of P, K and S fertilizers

Research has shown that small annual broadcast applications of P, K and S fertilizers will correct deficiencies and produce more consistent yields than will large initial application intended to last several years. Potassium requirements are more critical in mixed stands than in pure stands. This appears to be due to stronger competition for available K by grasses in the mixture. Therefore, on coarse textured soils and those with relatively low available K, fertilizer K should be applied to help maintain the legume component.

Because of the large amounts of nutrients required by a vigorously growing mixed forage and the fact that most of these nutrients are removed annually in the harvested forage, nutrient draw down from the soil is more rapid than with annual crops. As a result, nutrient supply in the soil should be monitored regularly by soil tests and noted deficiencies should be corrected with annual broadcast applications. The benefits of such treatments will usually be very obvious after 3 to 4 years by maintaining a more consistent grass-legume composition and by increased yield and forage quality.

The effect of N and P fertilizers on yield and forage composition was measured in a study of grass-legume forages in south-central Alberta. Experiments were established on existing stands at 16 locations where three rates of N (0, 28, 56 kg N/ha) and four rates of P (0, 12, 24, 36 kg P/ha) were applied annually in the spring for four years. Average DMY are shown in Table 18. Although N responses were consistent, yield increases tended to be small and were significant at only 25% of the experimental sites when no P was added. At several sites, yield response to added P was minimal in the first year of the study; however, yield increases became more apparent by the final year. The average yield response to N only exceeded the response to

P in the first year. Addition of 12 kg P/ha resulted in an average yield increase of 0.75 t/ha in the first year (Table 19). Further average yield responses were evident at P rates of 24 and 36 kg P/ha. The contribution of P to yield increase became larger with each successive year of fertilizer application. This study showed that yield response to P fertilizer was closely related to the supply of available P in the soil and the amount of precipitation in the year of application. On P-deficient sites, response increased with time, rate of P application and precipitation.

Table 18. Average annual dry matter yield (DMY) of smooth bromegrass-alfalfa stands in unfertilized check and with N or P application.

	DMY (t/ha)				DMY increase (t/ha)		
Year	Check	28 N§	56 N	24 P§	28 N	56 N	24 P
1979	4.57	5.09	5.36	4.99	0.52	1.79	0.42
1980	5.84	6.57	7.05	7.17	0.73	1.21	1.33
1981	5.71	6.72	7.13	7.21	1.01	1.42	1.50
1982	3.80	4.39	4.94	5.63	0.59	1.14	1.83

§ Kg/ha of N or P.

Table 19. Yearly increase in dry matter yield (DMY) of smooth bromegrass-alfalfa mixed stands from application of N or N plus P from 1979 to 1982.

	DMY increase (t/ha)§			
Year	0 P†	12 P	24 P	36 P
1979	0.66 (14)‡	0.75 (16)	0.85 (19)	0.93 (20)
1980	0.97 (17)	1.55 (27)	1.86 (32)	2.08 (36)
1981	1.22 (21)	2.16 (38)	2.29 (40)	2.59 (45)
1982	0.87 (23)	1.82 (48)	2.37 (62)	2.63 (69)

§ Based on average of treatments to which N was applied at 28 and 56 kg N/ha.
† Kg P/ha.
‡ Numbers in brackets are percent yield increases.

Results from this study also show that application of N stimulates the grass component of a grass-legume mixture (data not shown). This was particularly evident at the 56 kg N/ha rate where the grass/legume ratio was consistently higher than at the 28 kg N/ha rate. Annual P application stabilized or lowered the grass/legume ratios by stimulating the legume component in the mixture. Therefore, the temptation to apply high rates of N to mixed stands should be resisted because application of N can result in a weakening of the legume component with an associated decline in the contribution of the legume to future yield. After the initial year of fertilizer application, the most economic response may be achieved with the application of P in combination with modest amounts of N (*i.e.* usually no more than 20-25 kg N/ha, but the research information on N fertilizer requirements of various grass-legume compositions at a

given site is lacking in Alberta).

Tame Pasture Forage

Nitrogen (N) fertilizer application has been shown to produce dramatic DMY increases with bromegrass hay. Similar responses could be expected on grass stands that are pastured. In the past, N fertilizer was most commonly applied on forage land in the early spring. More recently, to overcome spring workload pressure and to try to ensure ample available N supply for early spring forage growth, fertilizer N has been applied in the fall.

Sources, times and methods of N application

Urea and ammonium nitrate are the primary fertilizer N sources used for application on grass pasture. Urea is the dominant form of granular N fertilizer available to farmers in western Canada. Surface broadcasting is the usual method of N application; however, under this condition urea is vulnerable to ammonia volatilization loss. Clearly, it is important to study ways for effective and efficient use of fertilizer N because of DMY and quality increases and the quantities of N required for high forage yields. Experiments conducted in central Alberta using urea and ammonium nitrate applied on established meadow bromegrass grown as simulated pasture compared N rates and determined the most effective time and method of N application (Tables 20, 21 and 22). Meadow bromegrass is a preferred grass species for pasturing.

As N fertilizer rate increased, DMY also increased to the maximum rate applied (300 kg N/ha) with both urea and ammonium nitrate (Table 20). Where no N was applied, DMY was low at both locations and when moderate and high rates of N were applied, DMY response was strong. At the 100 and 300 kg N/ha rates, average DMY with urea N at the Lacombe site was 2.27 and 3.43 times higher than the check and with ammonium nitrate as the N source it was 2.34 and 3.65 times higher. Similarly, at the Eckville site, average DMY with urea was 2.25 and 3.25 times greater than the check and the yield with ammonium nitrate was 2.45 and 3.47 times greater. At both locations and at all N rates, ammonium nitrate in spring applications produced larger DMY than urea did.

Effectiveness of N fertilizer applied in the spring and fall was determined on established meadow bromegrass (Table 21). When 100 Kg N/ha was applied at five different times in the fall, winter and spring, average DMY was highest for N applied in early fall and early spring for urea and ammonium nitrate at both locations. Average DMY was greater for ammonium nitrate than for urea for all times of application and at both locations. The least effective time of application was early winter for urea and late fall for ammonium nitrate. The relative average DMY response to N fertilizer compared with no N fertilizer was greatest at the Eckville location and was highest for ammonium nitrate at both locations (relative DMY: Lacombe, urea = 1.89, A.N. = 2.02; Eckville, urea = 2.36, A.N. = 2.79).

Table 20. Dry matter yield and protein yield of meadow bromegrass managed as simulated pasture by cutting four times, treated annually with seven rates of N applied in early spring as urea and ammonium nitrate at two locations in central Alberta (average of three years).

			Rate of applied N (kg N/ha)						
Site	Parameter	Fertilizer	0	50	100	150	200	250	300
Lacombe	DMY§	Urea	2.51	4.40	5.71	6.62	7.46	8.22	8.60
		A.N.‡		4.56	5.88	6.85	8.04	8.61	9.15
	PY†	Urea	250	478	701	880	1143	1297	1465
		A.N.		505	739	975	1228	1455	1613
Eckville	DMY	Urea	2.20	3.48	4.96	5.75	6.64	7.19	7.16
		A.N.		3.96	5.40	6.29	6.78	7.32	7.64
	PY	Urea	234	384	615	751	962	1106	1170
		A.N.		441	677	866	1099	1285	1415

§ Dry matter yield in t/ha.
† Protein yield in kg/ha.
‡ Ammonium nitrate.

Table 21. Dry matter yield (DMY) and protein yield (PY) of meadow bromegrass managed as simulated pasture by cutting four times, treated annually with 100 kg N/ha of urea and ammonium nitrate applied at different times in fall and spring at two locations in central Alberta (average of three years).

	DMY (t/ha)		PY (kg/ha)	
Fertilizer treatment	Lacombe	Eckville	Lacombe	Eckville
Check (Zero N)	2.77	2.17	276	178
Urea early fall	5.57	5.11	614	602
Urea late fall	4.93	5.09	538	590
Urea early winter	4.93	5.01	538	625
Urea early spring	5.47	5.22	637	663
Urea late spring	5.13	5.21	629	639
Average	5.21	5.13	591	624
A.N.[§] early fall	5.86	6.16	648	785
A.N. late fall	5.20	5.71	589	681
A.N. early winter	5.66	5.84	672	647
A.N. early spring	5.75	6.55	695	928
A.N. late spring	5.54	5.98	714	874
Average	5.60	6.05	664	783

[§] Ammonium nitrate.

In experiments to improve the effectiveness of urea N, several methods of N application were studied for treatments made in fall and spring. All N treatments were applied at a rate of 80 kg N/ha to a crop of established meadow bromegrass. Based on average DMY, the most effective method of urea application was disc-banding (bands 22.5 cm apart) in the fall or spring at both locations (Table 22). The surface-broadcast application method was least effective. No method of urea application was equivalent to ammonium nitrate broadcast in the spring. Ammonium nitrate when disc-banded in the spring produced slightly lower DMY than broadcast application. This may be due to fertilizer N in bands not becoming equally available to all plants early in the growing season, possibly because the band spacing was wider than optimum.

Effect of forage fertilization on animal performance

In a six-year field experiment (1956-1961) in central Alberta, the beef production potential of yearling Hereford steers was measured on three pasture crops (bromegrass-alfalfa mixture, bromegrass, and creeping red fescue) under three fertilizer treatments. Fertilizer application resulted in substantial increases in dry matter yield, animal weight gain and carrying capacity on all pasture types (Table 23). Average beef production on all pasture types in the first three years for the no fertilizer, N, and N plus P treatments was 209, 247, and 283 kg/ha, respectively. Similarly, the respective values for carrying capacity were 97, 117, and 126 days/ha/yr. Responses were even greater in the last three years when N and P application rates were considerably higher than for years one to three. Both animal weight gain and carrying capacity increased with the N and P

treatments, and the differences between treatments were greater in the last three years than in the first three years. On the pastures that received no fertilizer, animal weight gains were considerably lower in the last three years than in the first three years. Also, carrying capacity on the unfertilized grass pastures dropped markedly.

Table 22. Dry matter yield (DMY) and protein yield (PY) of meadow bromegrass managed as simulated pasture by cutting four times, treated annually with 80 kg N/ha of urea and ammonium nitrate using different methods of placement for fall and spring applications at two locations in central Alberta (average of two years).

Fertilizer treatment	DMY (t/ha)		PY (kg/ha)	
	Lacombe	Eckville	Lacombe	Eckville
Check (Zero N)	2.18	2.31	203	229
Urea broadcast early October	4.58	4.63	435	469
Urea band (disc) early October	5.50	5.11	573	558
Urea broadcast mid April	5.37	4.60	593	514
Urea band (disc) mid April	5.59	4.76	637	550
A.N.§ broadcast mid April	5.76	5.20	663	611
A.N. band (disc) mid April	5.37	5.09	605	598

§ Ammonium nitrate.

Results from this intensive study have demonstrated that N and P fertilizer applications on grass and mixed grass-legume pastures will produce substantial increases in beef gain and animal carrying capacity. The study also showed that when adequate plant nutrients are not supplied, the productivity of pastures declines quickly in terms of both plant and animal yield.

SOIL ACIDITY

Acidity in soil is determined by the measurement of the soil reaction (pH). Soil reaction is acid when pH is below 7.0; neutral at 7.0; and alkaline above 7.0. Soil reaction affects soil fertility and plant growth. For practical purpose, soils with reactions between pH 6.5 and 7.5 are considered neutral. Soils in the range of 5.6 to 6.0 are moderately acid and below 5.5 are strongly acid. Poor growth of an acid-sensitive crop, such as alfalfa, may indicate an acid soil condition.

Table 23. Dry matter production, liveweight gain and carrying capacity (steer-days/ha/yr) from three pasture types under three fertilizer treatments at Lacombe in central Alberta.

Fertilizer	Pasture types								
	Smooth bromegrass -alfalfa mixture			Smooth bromegrass			Creeping red fescue		
(kg N or P/ha)	DM (t/ha)	Gain (kg/ha)	Steer-days	DM (t/ha)	Gain (kg/ha)	Steer-days	DM (t/ha)	Gain (kg/ha)	Steer-days
Years 1-3									
No fertilizer	1.48	233	100	1.22	200	95	0.76	194	96
37 N	1.77	272	116	1.68	231	112	1.19	239	124
36 N + 45 P	1.87	297	121	1.94	238	124	1.37	268	132
Years 4-6									
No fertilizer	1.49	204	112	0.99	164	90	0.56	142	78
72 N + 90 P	2.56	373	164	2.23	354	148	1.86	330	132
144 N + 180 P	2.90	439	186	2.86	401	179	2.14	390	161

Reasons for Soil Acidity

There are two main reasons for soil acidification. Soils may be naturally acid due to the materials or processes involved in their formation. Thus, some soils become acid through time as a result of natural chemical and biological processes that are active in the soil all the time. The second way soils become acid is through man's activities which tend to speed up the natural acidification processes. Conversion of ammonium-N to nitrate-N by soil bacteria is an acidifying process. Therefore, the addition of ammonium N fertilizers can make soils more acid. Similarly, conversion of elemental S to sulphate by soil bacteria is also an acidifying process. The acidity equivalents of common N and S fertilizers are shown in Table 24. The theoretical values for N fertilizers may not necessarily be in agreement with results obtained in actual forage field experiments.

Table 24. Equivalent acidity of some N and S fertilizers.

Fertilizer	Equivalent acidity§
21-0-0 ammonium sulphate	5.4
34-0-0 ammonium nitrate	1.8
34-0-0 (11) "N plus S"	3.6
46-0-0 urea	1.8
82-0-0 anhydrous ammonia	1.8
0-0-0 (95) elemental sulphur	3.1

§ Equivalent acidity = kg lime ($CaCO_3$) to neutralize the acidity produced by 1 kg of N or S.
Source: Tisdale, S.L. and Nelson, W.L. 1966. Soil Fertility and Fertilizers. Macmillan Publishing Co., Inc. New York, NY.

Acidification of Soil by N Fertilizers

Application of N fertilizer to grass forage is essential in Alberta for the production of high yields of quality hay. However, concern exists that use of N fertilizer on forage will become a major factor causing further acidification of soils. This could cause problems with some forage crops.

Several long-term (5 to 16 years) experiments have been conducted in Alberta to determine the soil acidification from the application of various rates and sources of N fertilizer on bromegrass. In these experiments, soil samples were collected at various depths to determine the extent and depth of acidification. Annual application of 100 kg N/ha of ammonium nitrate for five years at two locations lowered the pH of the soil in the 0-7.5 cm depth and this effect was greater as the rate of N increased (Table 25). At the higher N rate, the pH tended to be influenced at the 7.5-15 cm depth, but there was no effect in deeper layers.

In a longer term experiment where ammonium nitrate was annually applied over a 16-year period, N had marked effect on soil acidification (Table 26). There was a close relationship

between the decrease in soil pH and the increase in N rate. Acidification was most pronounced in the 0-5 cm depth. Soil pH did not show a drop in the 5-10 cm layer until the N rate was 224 kg N/ha or more. During the period of this study, there was little effect on soil pH in the 10-15 cm layer or in deeper layers.

Table 25. Soil pH in N fertilized and unfertilized smooth bromegrass plots sampled after five years of ammonium nitrate application at Lacombe in central Alberta and Botha in east-central Alberta.

	pH of soil depths (cm)			
Rate of N	Lacombe		Botha	
(kg N/ha)	0-7.5	7.5-15	0-7.5	7.5-15
0	6.20	6.32	5.77	5.90
100	5.87	6.30	5.52	6.10
200	5.65	6.17	4.87	5.62

Table 26. The pH of soil layers after 16 years of ammonium nitrate application at seven rates to smooth bromegrass at Crossfield in south-central Alberta.

	Levels of applied N (kg N ha^{-1})						
Depth (cm)	0	56	112	168	224	280	336
	Soil pH						
0-5	7.07	6.47	5.62	4.87	4.32	4.32	4.27
5-10	7.12	7.25	7.32	7.12	6.50	6.03	5.05
0-15	7.30	7.15	6.98	6.37	6.20	5.40	5.25

Extractable aluminum (Al) is another component associated with soil acididty that can impact crop growth. High levels of soluble Al in soil are toxic to growing plants and solubility of Al often increases with increasing soil acidity. Therefore, extractable Al levels were determined in the above study and were found to increase in the 0-5 cm layer with higher N rates to the highest rate of 336 kg N/ha (data not shown). The Al concentration in the soil increased from 0.1 to 23.7 mg/kg when N rate increased from 112 to 336 kg N/ha. Soluble Al concentrations in the soil as low as 1-2 mg/kg are considered harmful to the growth of some crops such as alfalfa. Fortunately, there was no increase in Al concentration below the 5 cm level even at the highest N rate.

In another related study, urea and ammonium nitrate were annually applied at 112 kg N/ha in spring or fall for 11 years (Table 27). Both N sources caused the soil pH in the 0-5 cm depth to decrease. Urea tended to decrease pH more when spring applied than fall applied. Ammonium nitrate had a greater acidifying effect than urea.

A five-year experiment utilizing four different N fertilizers showed that the acidifying effect of N fertilizer varied with the source (Table 28). Soil pH was lowest in plots where ammonium sulphate was applied and the next lowest pH resulted with ammonium nitrate. Urea had less influence on soil pH of the surface layer than ammonium nitrate, while calcium nitrate slightly increased soil pH. Soil acidification only occurred in the 0-15 cm depth and was greater at the rate of 336 kg N/ha than at 168 kg N/ha. Also, at the higher rate, urea and ammonium nitrate lowered the soil pH at both the 0-5 and 5-10 cm depths and ammonium sulphate affected the soil pH in all depths to 15 cm.

Table 27. The pH of soil layers after 11 years of urea and ammonium nitrate application at 112 kg N/ha to smooth bromegrass at Crossfield in south-central Alberta.

Time of application	Source of N	pH of soil (0-5 cm)
	Check	7.08
Fall	A.N.§	5.87
	Urea	6.51
Spring	A.N.	5.85
	Urea	6.32

§ Ammonium nitrate.

Table 28. The pH of soil layers after five years of ammonium nitrate, urea, calcium nitrate and ammonium sulphate application at 168 and 336 kg N/ha to smooth bromegrass at Crossfield in south-central Alberta.

		168 kg N/ha				336 kg N/ha			
Depth (cm)	Check	A.N.§	Urea	C.N.	A.S.	A.N.	Urea	C.N.	A.S.
		Soil pH							
0-5	6.55	5.85	6.17	6.67	5.18	5.07	5.45	6.65	4.75
5-10	6.80	7.00	6.82	7.08	6.55	6.55	6.38	7.08	5.31
10-15	7.10	7.28	7.18	7.27	6.92	7.00	6.90	7.22	6.58
0-15	7.00	6.85	6.92	7.20	6.33	6.30	6.53	7.13	5.70

§ A.N., C.N. and A.S. refer to ammonium nitrate, calcium nitrate and ammonium sulphate, respectively.

The experiments show that N application on established bromegrass has a significant acidifying effect on the surface soil (0-15 cm). The greatest effect occurs near the surface (0-5 cm) where both acidity and extractable Al increased with higher N rates. Results of these studies indicate that long-term application of fertilizer N to bromegrass may require liming to counteract the soil acidification. This is particularly true if ammonium sulphate and ammonium nitrate are the primary N sources.

Longevity of Liming for Neutralizing Soil Acidity

Acid soils (pH 6.0 or lower) are less suitable for crop production than are neutral (pH 6.5-7.5) or slightly alkaline (pH 7.5-8.0) soils. Moderately acid soils can seriously reduce the yield of certain forage crops such as alfalfa. Lime ($CaCO_3$) may be applied to acid soils to neutralize the excess acidity. Lime, unlike most fertilizers, has a long term effect and therefore one application can correct the acidity and improve yields for many years.

Field experiments have been conducted in central Alberta to determine how long the liming effects last and how much crop yields are improved. Finely ground limestone was applied at rates ranging from 0 to 11 t/ha on soils at two locations in 1965 and 1967. Samples of surface (0-15 cm) soil were taken in various years to determine changes in soil acidity (Table 29). Results from these tests show that liming has an effect on soil pH within a year after application. Even at the lowest rates (2.2 and 4.4 t/ha), the pH was increased in the first year and that increase persisted through seven to nine years at both locations and up to 16 years at one location. Higher rates of lime had a greater influence on increasing soil pH levels.

Table 29. Effect of lime application in 1965 or 1967 on soil pH (0-15 cm depth) at two locations in central Alberta.

Rate of lime	Soil pH				
	Rocky Mountain House			Pendryl	
(t/ha)	1966	1974	1981	1968	1974
0	5.4	5.3	5.7	5.1	5.4
2.2	5.8	5.8	5.9	5.6	5.8
4.4	5.8	6.0	5.9	6.2	6.2
6.6	6.2	6.3	6.2	6.4	6.4
8.8	6.2	6.2	--	6.7	6.6
11.0	6.4	7.0	6.5	6.9	6.9

Alfalfa grown periodically at these experimental locations showed marked response to the lime applications (Table 30). Again, the lowest rate of lime application resulted in substantial yield increases (1.9 and 1.5 t/ha) at both locations shortly after application. Also, the greatly improved production persisted for 16 years at the location where alfalfa was grown.

These results show that production of alfalfa can benefit greatly from lime applied to reduce acidity. In addition, the results demonstrate that a single application of lime, made at a rate sufficient to raise the soil pH to 6.0 or more, will have a neutralizing effect lasting 10 to 16 years. Because of this long-lasting effect, the cost of applying lime to acid soils should be considered a capital investment cost that is amortized over several years.

Table 30. Effect of lime application in 1965 or 1967 to acid soil on alfalfa hay yields at two locations in central Alberta.

Rate of lime (t/ha)	Yield of hay (t/ha)			
	Rocky Mountain House			Pendryl
	1966	1974	1981	1969
0	0.7	2.4	1.1	0.9
2.2	2.6	4.4	2.4	2.4
4.4	2.6	4.4	2.6	2.9
6.6	2.6	4.4	3.3	2.6
8.8	2.4	4.2	4.0	2.6
11.0	2.9	4.2	4.2	2.9

CONCLUSIONS

Forage acreage represents a significant proportion of the agricultural land base in Alberta. However, proper fertilization is a low priority. Effective forage management must include proper fertilization based on soil tests and efficient fertilizer application.

Soil testing is critical for proper forage establishment and maintenance of the stand. Soil testing can identify nutrient deficiencies and other soil restrictions prior to establishing the forage. To maintain a productive forage stand, soil testing is an effective and essential tool to monitor nutrient levels and for developing proper fertilizer recommendations.

Effective fertilizer application is greatly influenced by forage type, time of application, method of application and fertilizer source. The legume content of the mixed forage will have a major impact on the N fertilizer requirements but will also have impact on P, K and S requirements. With proper inoculation, forages with a high proportion of legumes (greater than 80%) require no N fertilizer. Mixed forage stands with 40 to 60% legume require little N fertilizer. Forages with low or no legume content will require larger amounts of N fertilizer. Phosphorus, potassium and sulphur fertilizer requirements will also vary with the forage type. Fertilization prior to seeding a forage is critical for establishing a forage stand especially for less mobile nutrients such as P and K. For an established stand, broadcast application is currently the most practical method of applying fertilizers, however, timing and source of fertilizer will have a significant effect on fertilizer use efficiency and stand productivity. In general, fertilizers are more effective when applied in early spring than fall or late spring. In high moisture areas and under irrigation, N fertilizer can be split into two applications, (i.e. early spring and after the first cut). For sources of N fertilizer, ammonium nitrate is more effective than urea when broadcast on an established stand. However, supplies of ammonium nitrate are limited and it is more expensive. Effectiveness of urea can be improved by disc-banding the fertilizer below the soil surface, but more research is needed to properly identify conditions that may affect urea efficiency.

Across Alberta, forage response to fertilizer application will vary due to climatic conditions and soil types. Moisture has a major impact on forage growth and nutrient requirements. In drier regions forage response will be low and more variable, while in wetter regions forage response will be consistently higher and more uniform. With proper fertilizer management, forage productivity can be greatly enhanced by promoting maximum dry matter production, extending the longevity of the stand and producing high quality feed material for livestock.

RECOMMENDATIONS

Climate and soil type have a significant effect on forage response to fertilizer application, while forage composition will affect the overall nutrient requirements. Fertilizer requirements for pure stands of grasses or legumes are very straight forward, however, it is much more difficult to develop an effective fertilizer program for mixed grass-legume stands.

Fertilizing to Establish a Forage Stand

A critical factor in forage stand management is proper establishment. This includes:

1. Soil sampling and testing prior to establishment to properly assess the nutrient status of the soil and to identify any possible soil limitations, i.e. acidity and salinity.

2. Selection of the best forage species and variety for the intended use, soil type and climate.

3. Application of the required fertilizers prior to seeding, particularly on very deficient soils.

4. Proper inoculation and handling of legume forage seed.

5. Proper timing, rates and methods for seeding.

Fertilizing to Maintain a Forage Stand

Fertilizer application to an established forage stand is essential to maintain the productivity and longevity of the stand. This includes:

1. Regular soil sampling and soil testing to determine the type and amount of fertilizer to apply.

2. Soil sampling and tissue sampling to diagnose problem situations and to monitor changes that may occur in soils and crops.

3. Annual fertilizer applications are usually more effective than large initial single application made at the time of establishment for all forage types.

4. Early spring fertilizer application is generally more effective than fall or late spring application for all forage types, but the effectiveness of fall-applied N can be improved by disc-banding the fertilizer below the soil surface.

5. Split applications of N fertilizer as opposed to one time annual application for grass or low legume forages should be used only in high moisture areas and under irrigation.

6. Urea is less effective than ammonium nitrate as a source of N fertilizer for established grass forages, but its effectiveness can be improved by disc-banding the fertilizer below the soil surface. Even though urea may be less effective than ammonium nitrate, it is still a very good source of N for fertilizing forage crops.

7. Liming acid soil will increase forage production and the life of the forage stand.

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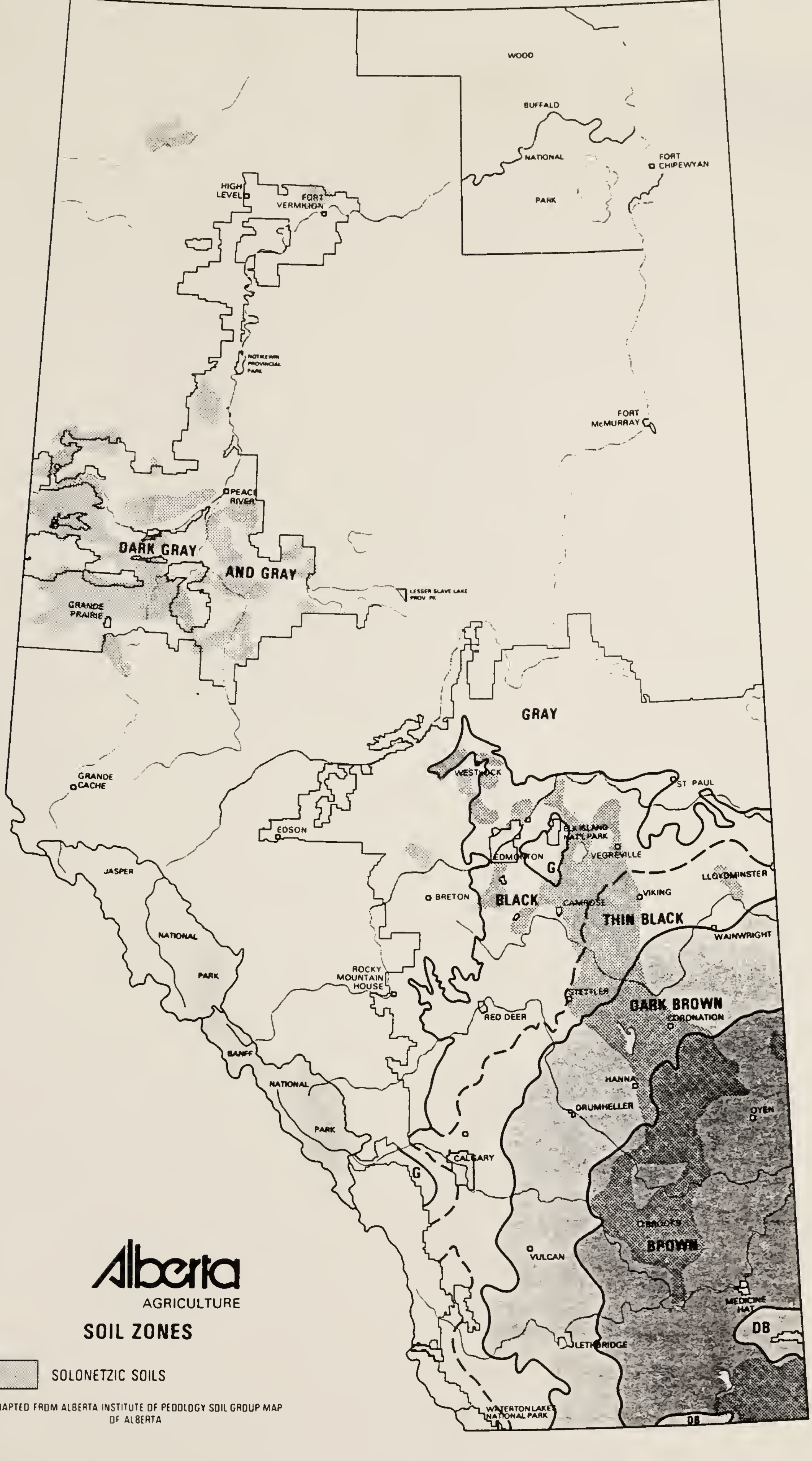
APPENDICES

Table 1 General range of fertilizer requirements for forage crops in Alberta (kg/ha)[1].

Forage	Nutrient	Brown	Dark Brown	Thin Black	Black	Gray Wooded	Irrigated
Legume	N	0	0	0	0	0	0-40
(80-100%)	P_2O_5	20-40	20-40	20-50	20-60	20-60	20-60
	K_2O	0	0	0	0-40	0-40	0
	S	0-20	0-20	0-25	0-30	0-30	0-30
Grass-legume	N	0	0	0	0	0	0-40
(60-80% legume)	P_2O_5	20-40	20-40	20-50	20-60	20-60	20-60
	K_2O	0	0	0	0-40	0-40	0
	S	0-20	0-20	0-25	0-30	0-30	0-30
Grass-legume	N	0	0	0-10	0-30	0-20	0-40
(40-60% legume)	P_2O_5	20-40	20-40	20-50	20-60	20-60	20-60
	K_2O	0	0	0	0-40	0-40	0
	S	0-20	0-20	0-25	0-30	0-30	0-30
Grass-legume	N	20-40	30-50	40-70	50-90	40-80	70-150
(20-40% legume)	P_2O_5	20-40	20-40	20-50	20-50	20-50	20-50
	K_2O	0	0	0	0-40	0-40	0
	S	0-15	0-15	0-20	0-20	0-20	0-20
Grass	N	40-80	40-80	80-120	90-140	80-130	120-200
(80-100%)	P_2O_5	20-40	20-40	20-50	20-50	20-50	20-50
	K_2O	0	0	0	0-40	0-40	0
	S	0-15	0-15	0-20	0-20	0-20	0-20

[1] Specific fertilizer requirements should be based on soil test recommendations.
Source: Alberta Agriculture Soils and Animal Nutrition Laboratory, Edmonton, Alberta.



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